NASA Technical Memorandum 89194

Near-Field Deposition Patterns Of Chlorides And Particulates Resulting From Launches Of The Space Transportation System At The John F. Kennedy Space Center

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ABSTRACT

The assessment of environmental impacts resulting from launches of the Space Transportation System (STS) requires quantification of deposition patterns and identification of chemical constituents of exhaust products, especially those produced by the Solid Rocket Boosters. During launches 41-B (STS-11), 41-C (STS-13) and 41-D (STS-14) up to 100 bulk deposition collectors, 83 mm in diameter containing 100 ml of deionized water, were placed in a grid pattern covering 12.6 ha north of Launch Pad 39A. Estimates of chloride (primarily in the form of HCl) and particulate deposition patterns and levels were made based on laboratory measurements of materials entrained in the bulk collectors. Estimated maximum ranges of chloride and particulate deposition within the sample area outside the launch pad perimeter fence were from 0 to 127 g/m^2 and 0 to 246 g/m^2, respectively. These measurements represent worst case near-field deposition of approximately 3.4×10^3 kg of chlorides and 7.1×10^3 kg of particulates. Deposition patterns were highly influenced by wind speed and direction. Captured particulates consisted of a variety of materials including Al_2O_3, pad soils, sand and sea shell fragments, fire brick fragments, paint chips, iron flakes, and vegetation debris. Under worst case conditions, when winds are from the south, approximately 1.7×10^3 kg of HCl are deposited directly to each of the aquatic and terrestrial ecosystems north of Launch Pad 39A. Buffering this acid deposition requires a calculated equivalent of 4.7×10^3 kg of $CaCO_3$. The continued consumption of acid neutralizing compounds in the environment may result in alterations of soil and water chemistry directly impacting habitat quality. Based on this investigation, these impacts should be limited to the near-field area (15-25 ha) in the vicinity of STS launch complexes.

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I. INTRODUCTION

Recent and projected increases in the industrialization of space through the developing Space Transportation System (STS) and planned manned space stations suggest that there will be a continued expansion of the number of flights from both U.S. launch sites. During each STS launch a ground cloud is formed that consists of: 1) the exhaust products of the Solid Rocket Boosters (SRB) and the Shuttle Main Engines (SME); 2) products of afterburning in the exhaust plume; and 3) the water, air and ground debris mixed with exhaust gases at the launch pad (Figure 1) (NASA 1979). A list of primary chemicals released by SRB ignition is presented in Table 1. Two components, hydrochloric acid (HCl) and aluminum oxide particulates (Al_2O_3) have been identified as constituents of primary concern (NASA 1979). During the first 10 seconds of a STS launch event approximately 1.7×10^4 kg of HCl and 2.8×10^4 kg of Al_2O_3 are released by the two SRB's (Bjorklund et al. 1982, Anderson and Keller 1983). These exhaust products, in combination with water from the sound suppression and deluge system, are jetted from the flame trench at a rate of 80-85 meters per second producing a ground cloud that occupies a volume of approximately 1.4×10^6 m^3 (Anderson and Keller 1983). The ground cloud has an acid normality of two with undetermined quantities of a variety of materials including but not limited to Na, Si, P, S, K, Ti, V, Cr, Mn, Fe, Cu, Ni, Zn, and Pb (UCF/FSU 1982, Potter 1983).

From an ecological perspective, the problem of assessing environmental impacts produced by STS launches can be addressed by examining the biogeochemical cycling of exhaust products. This concept generally recognizes the watershed as the physical boundary of the ecosystem of concern with the hydrologic cycle considered as a primary forcing function for movement of materials through the system. Chemicals deposited on the watershed which are not biologically or chemically bound (assimilated) are carried fairly rapidly to the aquatic system (Likens 1981). Thus, to begin evaluations of impacts it is necessary to define the areal extent, chemical make-up and quantity of depositional loadings resulting from STS launches. As the assimilative capacity of the watershed is exceeded the transport of these materials to surrounding areas and into the groundwater will accelerate.

The objective of this study was to quantify the loading rates and deposition patterns of chlorides and particulates in the near-field vicinity of Launch Pad 39A. Information derived from this evaluation will be useful in assessing impacts at Launch Pad 39A and in the development of hypotheses regarding environmental impacts that may be encountered at Launch Pad 39B at KSC and at SLC-6 on Vandenberg Air Force Base. Quantification of near-field deposition will also allow for refinement of the Rocket Exhaust Effluent Diffusion Model.

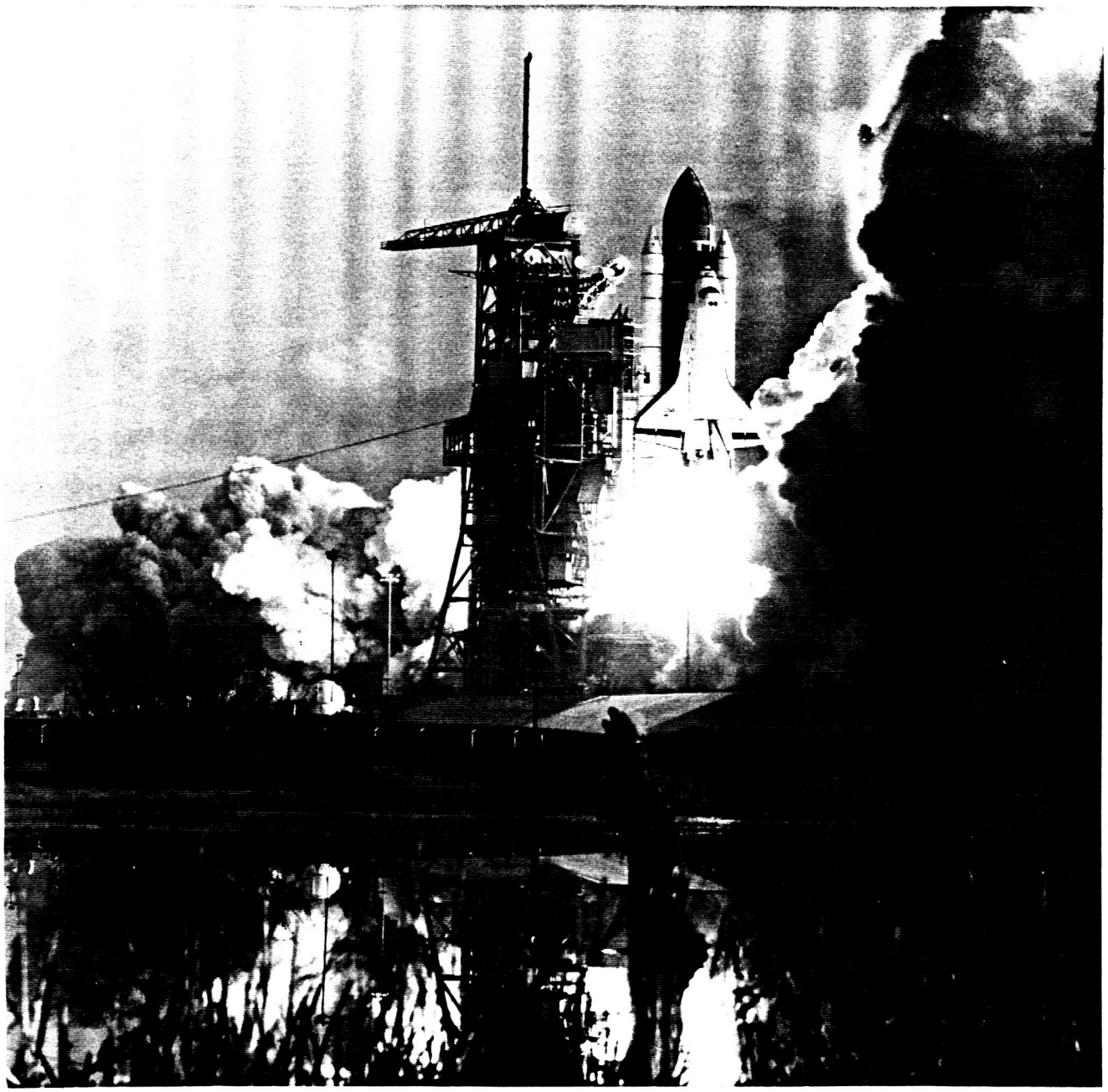

Figure 1. Photograph of an STS launch from Launch Pad 39A at Kennedy Space Center showing the Solid Rocket Booster exhaust cloud (left side of photograph) and the Space Shuttle main engine exhaust cloud (right side of photograph).

Table 1. List of major chemicals in the exhaust of the Solid Rocket Boosters used on the Space Transporation System. Weights are based on estimates of the amount of fuel expended during the first ten seconds of flight.[1]

Exhaust Product	Weight (kg)	Percent
AlCl	6.3	0.0068
AlClO	7.3	0.0079
$AlCl_2$	29.9	0.0321
$AlCl_3$	4.6	0.0049
H	17.3	0.0186
H_2	1.8×10^3	1.8829
HO	30.0	0.0323
H_2O	9.8×10^3	10.4875
N_2	8.2×10^3	8.7728
NO	2.0	0.0022
HCl	1.7×10^4	21.6872
CO	2.1×10^4	22.8433
CO_2	3.7×10^3	4.0188
Al_2O_3	2.8×10^4	30.2046

[1]Modified from NASA 1978, 1979 and information provided by Morton Thiokol, Inc.

II. METHODS AND MATERIALS

The study site covered an area 420 m by 300 m outside the perimeter fence north of Launch Pad 39A (Figure 2). Bulk deposition collectors (plastic jars) with an inner diameter of 83 mm and a depth of 86 mm were attached to metal poles in a grid pattern established during previous vegetation surveys by Schmalzer et al. (1985). Collectors were attached above existing vegetation height or approximately 10 cm above the water surface for samples in the lagoon. Approximately 100 ml of deionized water were placed in each collector to aid in the retention of deposition.

A maximum of 100 covered collectors were deployed two days prior to launch. Collections were made during launches of missions 41-B (STS-11) on February 3, 1984; 41-C (STS-13) on April 6, 1984 and 41-D (STS-14) on August 30, 1984. Lids were removed approximately 24 hours before launch. Six control collectors were placed to the southeast of Launch Pad 39A and were used to establish background deposition levels of chlorides and particulates. These values were subtracted from measurements obtained at the study site after launch to account for ambient deposition.

The collectors were capped, removed from the poles, and transported to the laboratory within eight hours following launch. Aliquots were removed from each collector and analyzed for chloride concentrations using a specific ion electrode (USEPA 1979). The total volume of water in each collector was measured and the particulate material was transferred, by washing with distilled water and scraping, to a Millipore filter funnel containing a preweighed 4.2 cm glass fiber filter. Filters were dried overnight (105°C) and reweighed, in a manner similar to the technique used to measure suspended solids in surface waters (USEPA 1979). Total chloride and particulate values for each collector in g/m^2 were calculated using the water volume concentration values (minus background) and a bulk collector surface area of 53.5 cm^2. Microscopic examination of the dried filters was made using a Bausch and Lomb stereo zoom dissecting microscope and photographs were taken using a Polaroid camera attachment.

Isopleth maps were made of chloride and particulate deposition patterns at a scale of 1:1130 and overlaid onto a 1:2260 aerial photograph using a pantograph. Areas between isopleths were measured on the 1:1130 map with a MGT-2 Metrigraphic Terminal (H. Dell Foster Co.) and the total area of deposition was estimated by multiplying the area bordered by the isopleths by the sum of the value of the isopleths divided by two.

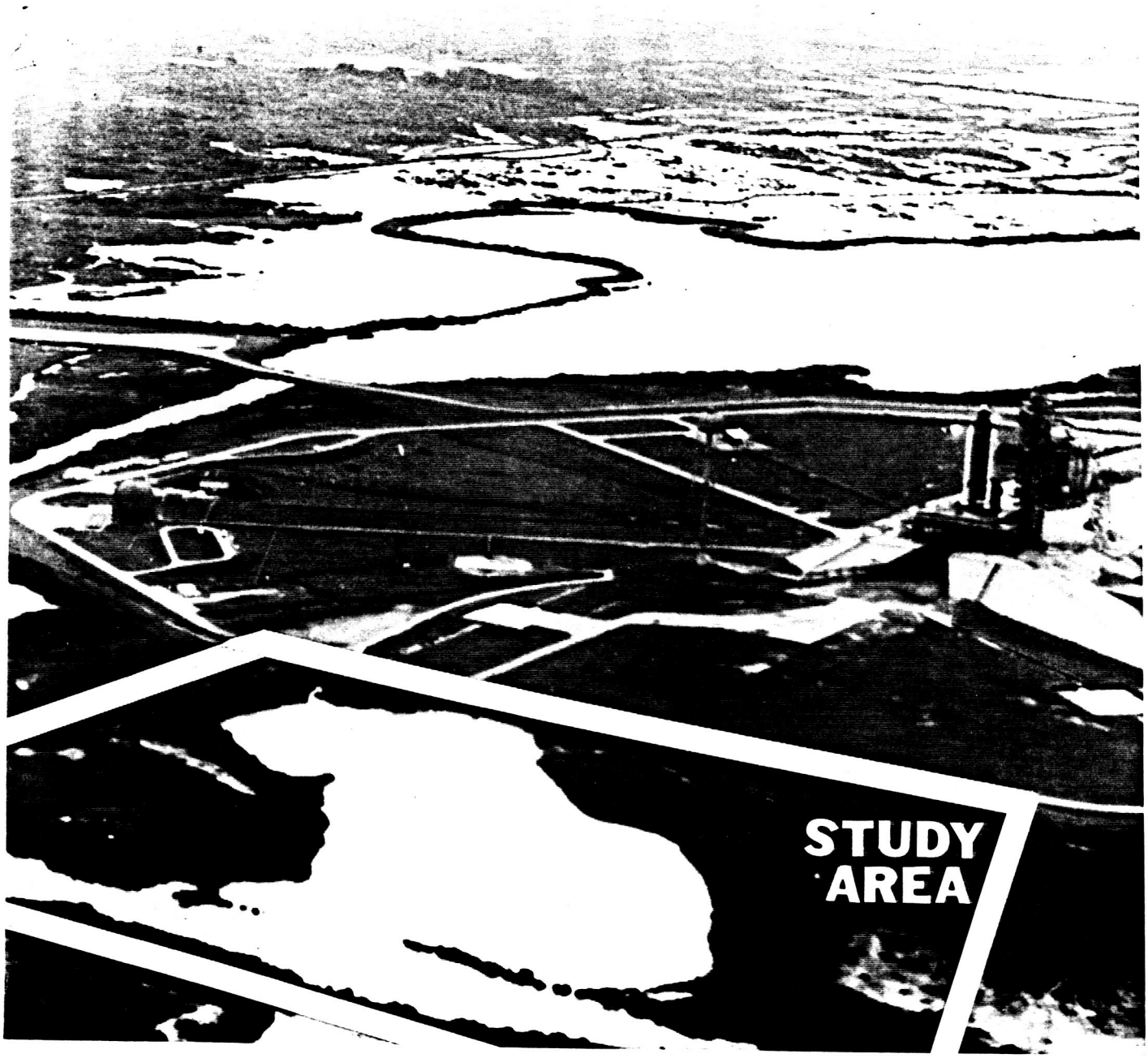

Figure 2. Photograph of Launch Pad 39A and the 420 x 300 meter study site north of the pad perimeter fence.

A second aspect of this study involved the assessment of a potential source of data bias resulting from the use of 100 ml deionized water as a capture medium. It was speculated that HCl loss through evaporation might be significant. Two methods were utilized to estimate evaporative losses. In the first method, droplets were produced using a microliter syringe to match the outline left on the wall of the collector. Two drop sizes were used with the larger being approximately 5 ul and the smaller about 0.5 ul.

The equation used to calculate evaporative loss was as follows:

$$HCl\ (g/m^2) = A \times B$$

Where:
- A = the acid droplets were 2N (Normal) or 74 ug/ul of HCl.
- B = the estimated volume of the droplets on the inside wall of the collector.

This value was then converted to an estimate of g/m^2 based on the surface area of the collector.

The second method utilized results reported by Anderson and Keller (1983) from copper plate measurements collected near the pad perimeter fence. The following equation and assumptions were made and the values used were believed representative of a worst case situation (i.e., maximum HCl loss due to evaporation).

$$HCl\ (g/m^2) = A \times B \times C \times D \times 1/E \times 1/F \times G$$

Where:
- A = the average droplet size, which was less than 0.3 mm radius, or approximately 0.1 ul.
- B = the acid droplets were 2N or 74 ug/ul of HCl.
- C = the number of droplets on the 810 cm^2 copper plate (3.7 per cm^2).
- D = the exposed area of the inside wall of the collector, 198 cm^2.
- E = the surface area of the collector mouth, 53.5 cm^2.
- F = the number of ug per gram.
- G = the number of cm^2 per m^2.

These assumptions and values were then used to estimate the amount of HCl loss due to evaporation.

III. RESULTS AND DISCUSSION

Particles collected in the bulk collectors ranged in size from submicron to about 4 mm diameter (Figure 3). These included aluminum oxide dust, fine sand, coarse sand, fine gravel, shell

Figure 3. Photograph of the variety of deposition particles collected in the near-field as a result of the launch of 41-B (STS-11) (magnified 8X). Clockwise from upper left: transparent matrix, fine gravel, Iron oxide, coarse sand, fine sand, aluminum oxide.

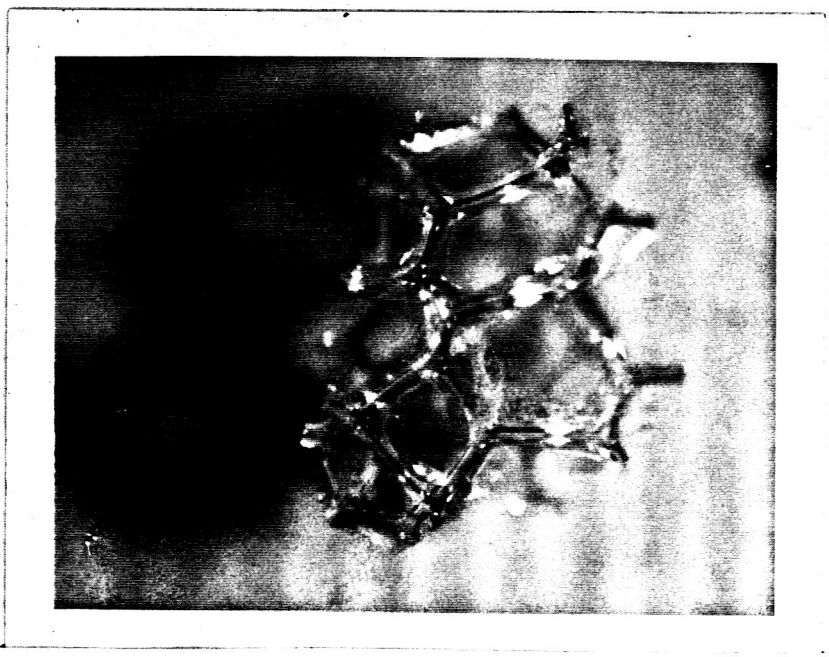

Figure 4. Photograph of the transparent matrix material collected during the launch of 41-B (STS-11) (magnified 56X).

fragments, pieces of fire brick, iron oxide particles, and vegetation debris. In many collectors, another material was found which also appears in Figure 3 and is shown in closeup in Figure 4. In each case this material appeared as a clear "matrix" of fibers or bars joined to form 4 to 6 sided polygons, producing clusters typically 1 to 2 mm across. The source of this material is unknown.

Estimated maximum ranges of chloride deposition were from 0 to 127 g/m^2. Particulate deposition ranged between 0 and 246 g/m^2 across the study area. Maximum values were recorded from launch 41-D (STS-14). Estimates of total chloride and particulate deposition to the aquatic and terrestrial systems north of Pad 39A for the three launches are presented in Table 2.

Values for 41-B (STS-11) and 41-D (STS-14) are similar for both chloride and particulate deposition and represent the worst case for a single launch. The ground cloud passed directly over the study area. The lower deposition values for 41-C (STS-13) are a result of the limited area within the study site directly impacted by the ground cloud. They do not represent a reduction in total deposition, only a change in the deposition pattern.

Results from the evaluations of HCl loss due to evaporation indicated the following:

1) A worst case estimate of the amount of HCl lost was made using a collector from the area of highest deposition. The collector had approximately 200 small drops (0.5 ul) and 50 large drops (5.0 ul) on the inner wall or 0.25 ml of HCl. The estimate of total HCl lost equaled 3.5 g/m^2.
2) The worst case estimate based on previous copper plate studies was 1.0 g/m^2.

These amounts, if real, would produce very little difference in the isopleth maps and estimates of HCl deposition in the study site. Also, it is believed that the values are well within the error levels inherent to the analytical techniques used. Thus, the use of 100 ml of deionized water as a collection medium appears valid.

Results from this study of deposition patterns, in the form of isopleth maps for chlorides and particulates, are presented in Figures 5 through 10. Highest concentrations of deposition occurred immediately in line with the flame trench north of Launch Pad 39A. The pattern of deposition was controlled by ambient meterological conditions as seen when comparing deposition patterns of 41-B (STS-11) and 41-D (STS-14) with 41-C (STS-13). During launch of mission 41-C (STS-13) winds at the time of launch were from the north west (300°) at approximately 5 meters/second. This wind was sufficient in velocity to turn the exhaust plume across the south east section of the study area.

Table 2. Ranges of chloride and particulate loading rates to the aquatic and terrestrial ecosystems north of launch pad 39A resulting from STS launches 41-B (STS-11), 41-C (STS-13) and 41-D (STS-14)[1].

STS Mission#	Aquatic Ecosystem	Terrestrial Ecosystem	Total
41-B			
Chlorides	1.7×10^3 Kg	1.7×10^3 Kg	3.4×10^3 Kg
Particulates	3.5×10^3 Kg	3.6×10^3 Kg	7.1×10^3 Kg
41-C			
Chlorides	0.3×10^3 Kg	0.2×10^3 Kg	0.5×10^3 Kg
Particulates	1.0×10^3 Kg	0.7×10^3 Kg	1.7×10^3 Kg
41-D			
Chlorides	1.7×10^3 kg	1.6×10^3 Kg	3.3×10^3 Kg
Particulates	4.0×10^3 Kg	3.1×10^3 Kg	7.1×10^3 Kg

[1]Estimates are based on isopleth areas and deposition levels outlined in Figures 5 to 10.

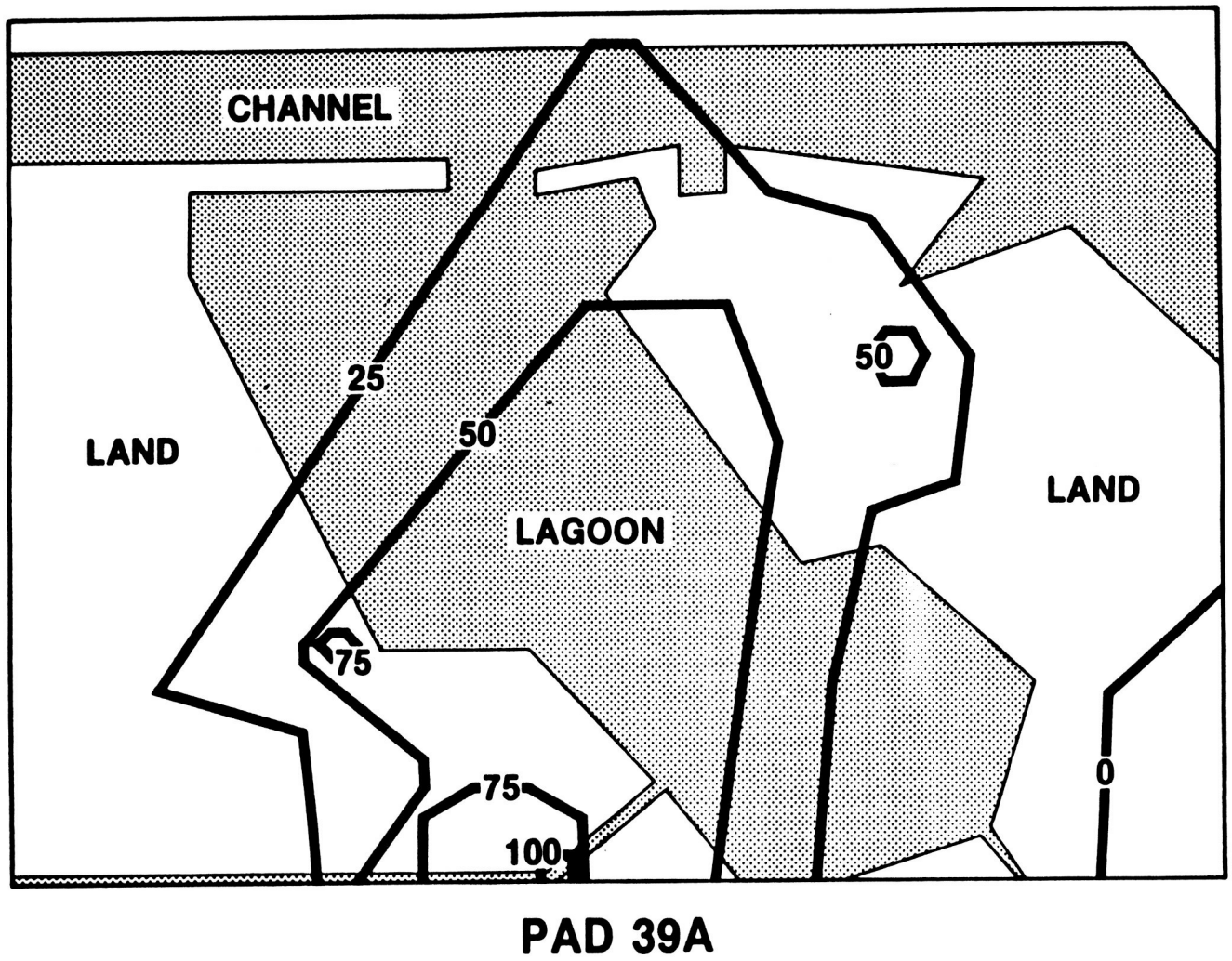

Figure 5. Estimated chloride deposition pattern (g/m^2) across the study site resulting from launch 41-B (STS-11) on February 3, 1984. (Scale 1:2600.)

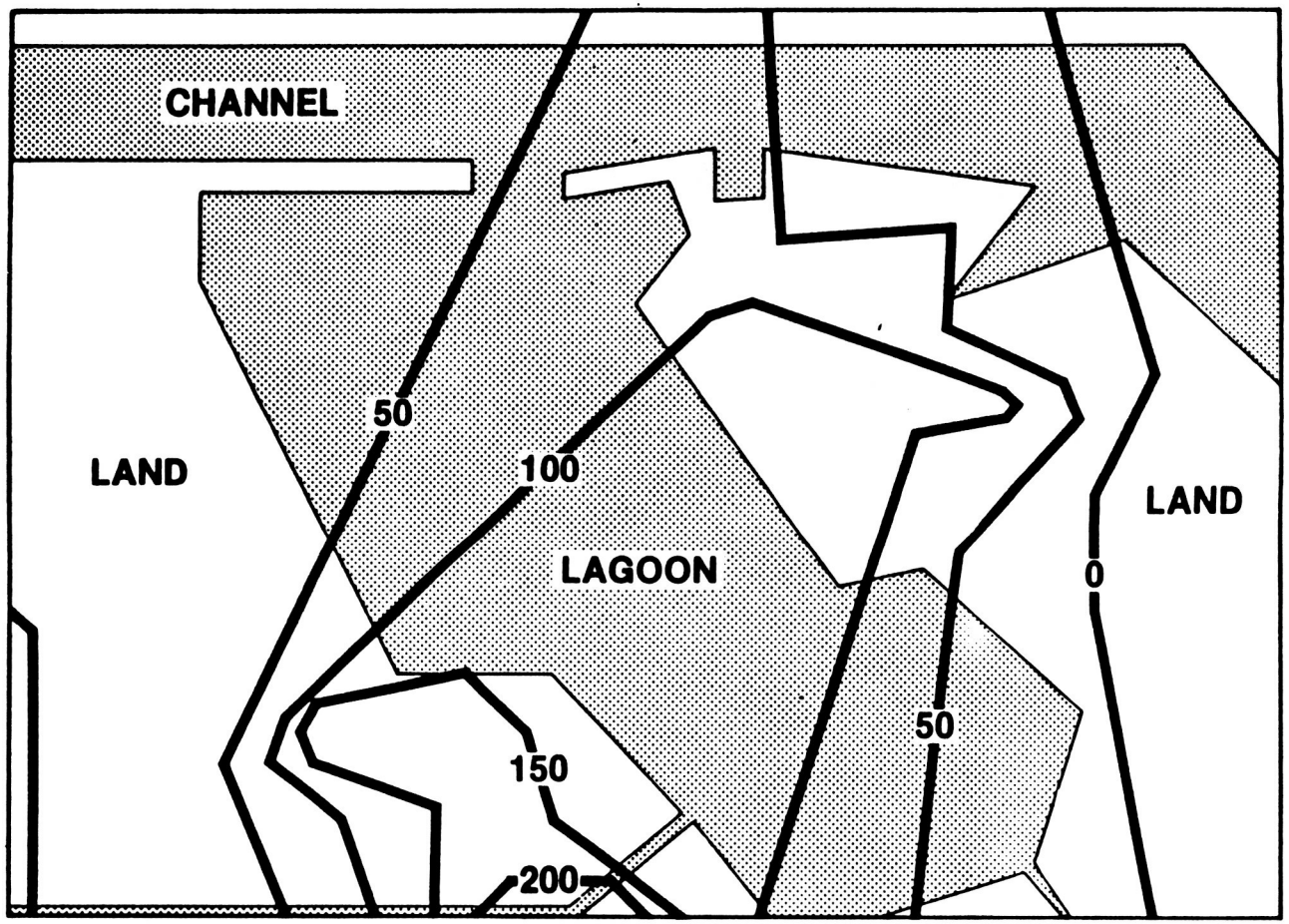

Figure 6. Estimated particulate deposition pattern (g/m^2) across the study site resulting from launch 41-B (STS-11) on February 3, 1984. (Scale 1:2600.)

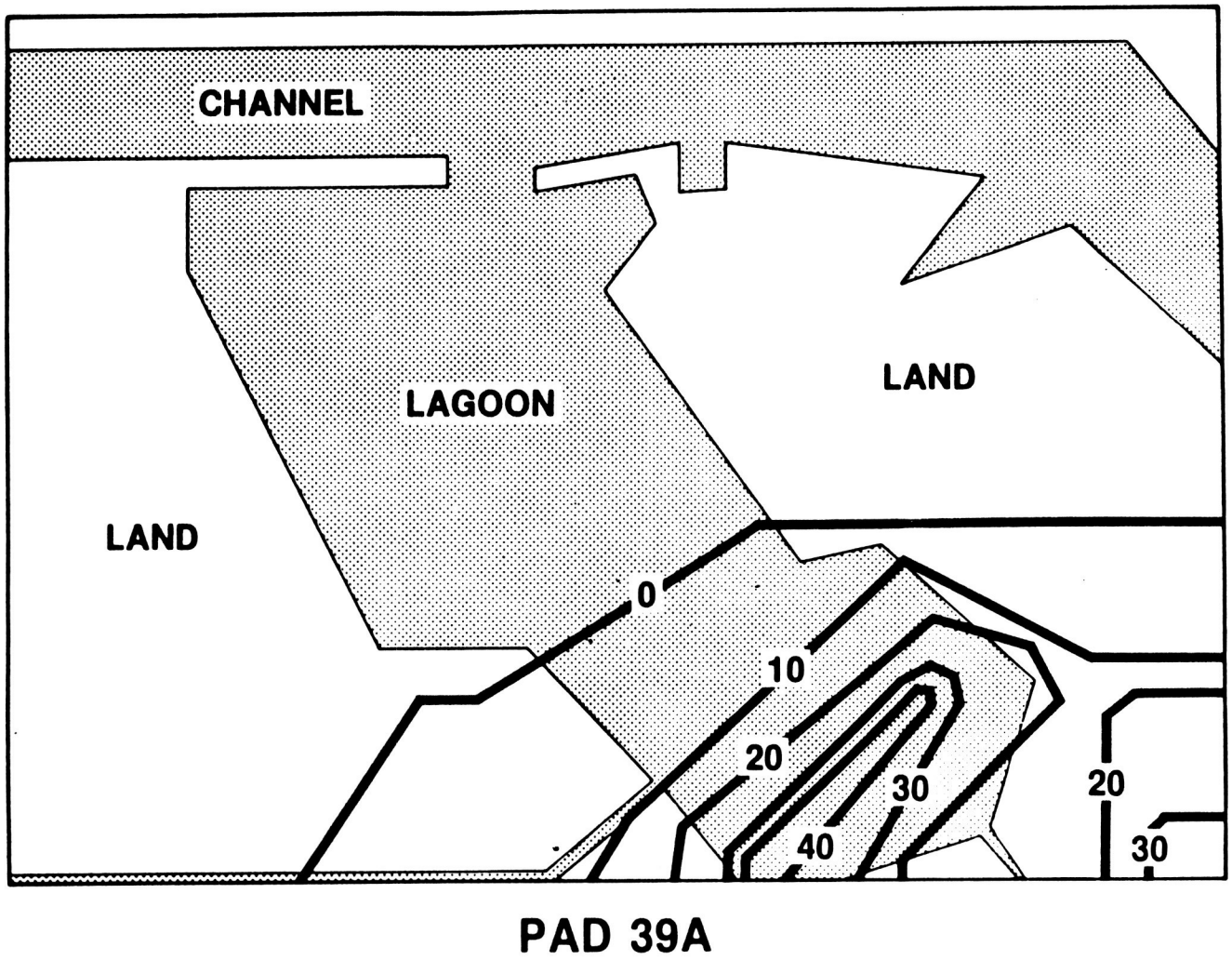

Figure 7. Estimated chloride deposition pattern (g/m^2) across the study site resulting from launch 41-C (STS-13) on April 6, 1984. (Scale 1:2600.)

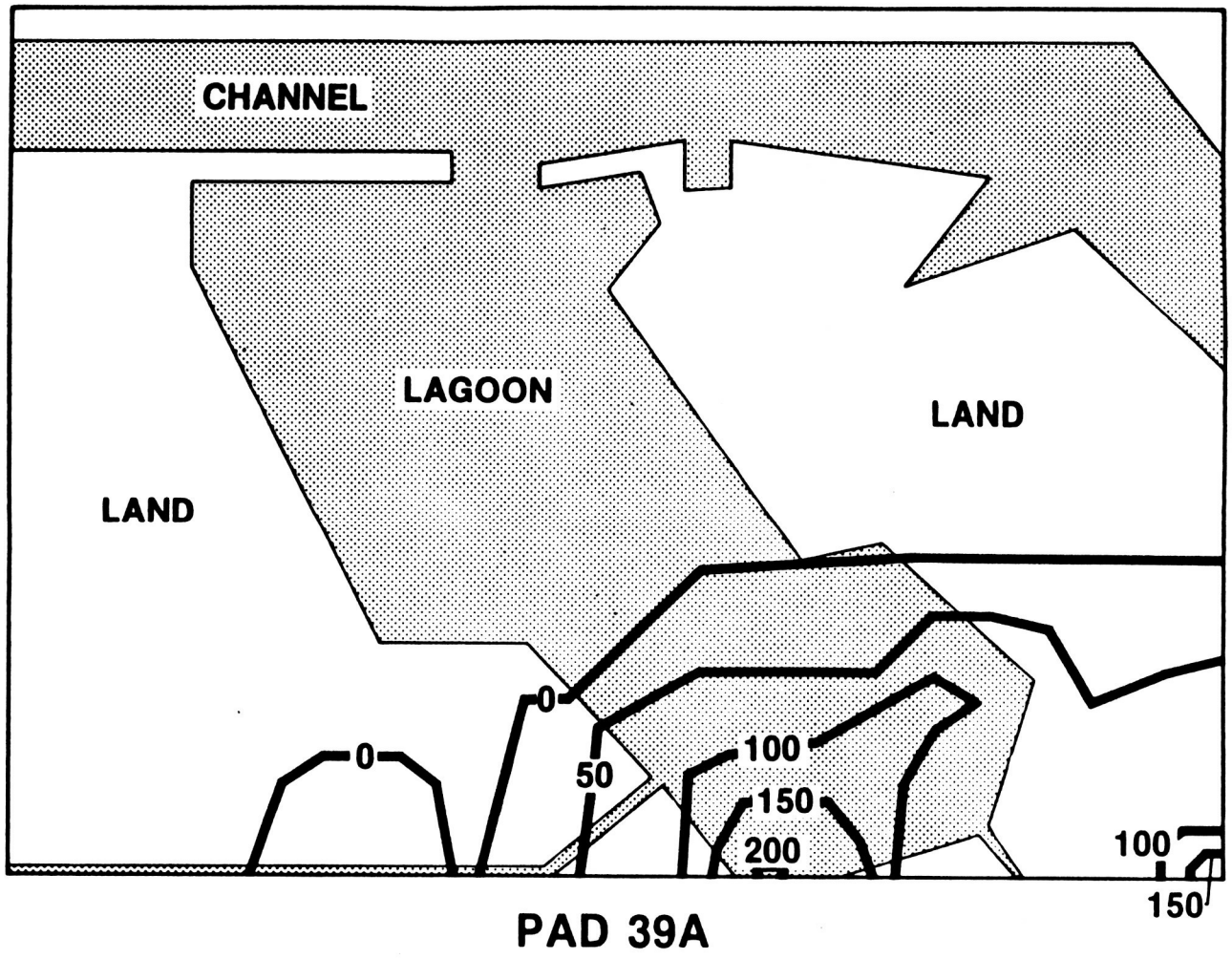

Figure 8. Estimated particulate deposition pattern (g/m^2) across the study site resulting from launch 41-C (STS-13) on April 6, 1984. (Scale 1:2600.)

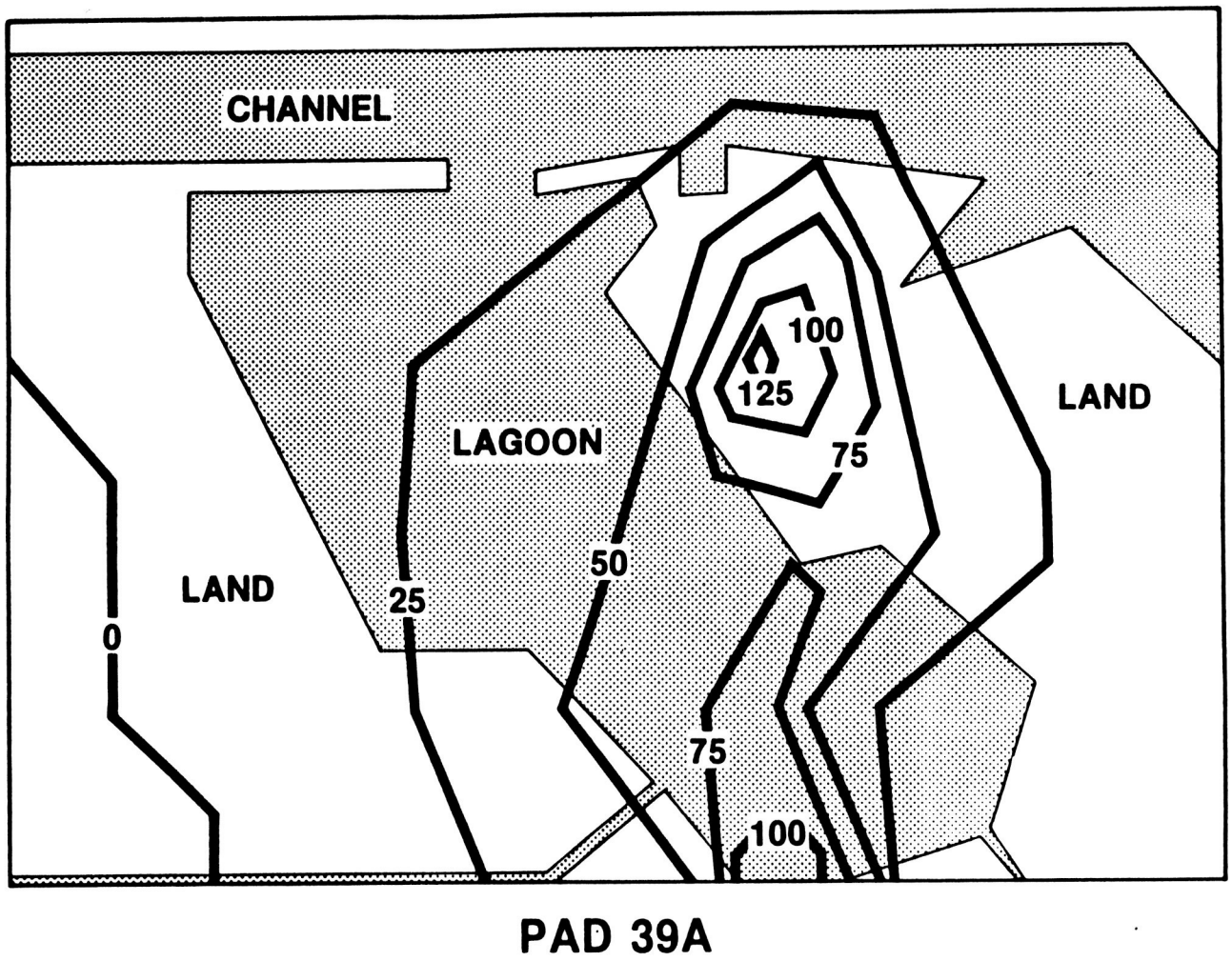

Figure 9. Estimated chloride deposition pattern (g/m^2) across the study site resulting from launch 41-D (STS-14) on April 30, 1984. (Scale 1:2600.)

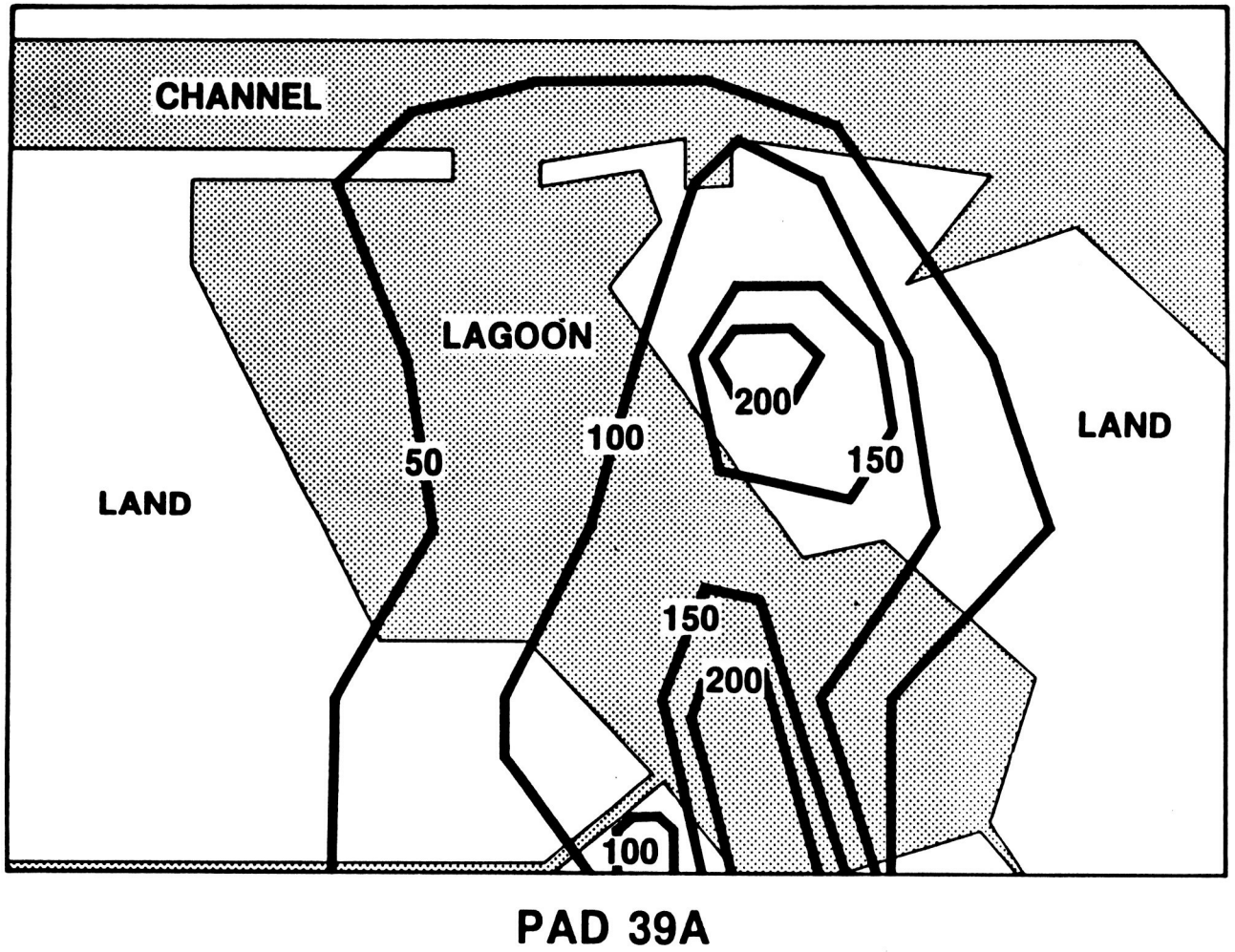

Figure 10. Estimated particulate deposition pattern (g/m^2) across the study site resulting from launch 41-D (STS-14) on April 30, 1984. (Scale 1:2600.)

Surface winds during missions 41-B and 41-D were directed from the south (180°) at 1.1 meters/second and at 0.9 meters/second, respectively. Deposition patterns resulting from these two launches displayed only minor deviations away from the center line of the Launch Pad 39A flame trench. The variability of near-field deposition patterns produced by STS launches is further documented in Figure 11 which displays, on a larger scale, the cumulative near-field deposition pattern as defined by visual inspection of vegetation damage resulting from STS launches 1 through 9 (Schmalzer et al. 1985).

Measurements of chlorides are roughly equivalent to HCl (HCl is 97 percent chloride by weight), thus under the worst case situations the study site receives 17 percent of the 1.7×10^4 kg of HCl produced during the first 10 seconds of a launch. In addition, chlorides measured in the two deluge water holding ponds after launch of flight 41-B represented approximately 2,000 kg of HCl or about 11 percent of the initial 10 second burn. From these calculations the fate of 28 percent of the HCl produced during the 10 seconds of ground cloud formation could be accounted for. It is important to note that more HCl is deposited outside the pad fence than is retained in the holding ponds after launch and pad wash-down.

The problem of acid deposition resulting from STS launches is primarily one of a system imbalance due to the increased input of acid-forming HCl to the ecosystem. Based on the worst case HCl loading of 3.4×10^3 kg it will require an equivalent in acid neutralizing capacity of 4.7×10^3 kg of $CaCO_3$ to buffer the acid deposition. As the annual rate of deposition increases with increasing launch rates, the capacity of the terrestrial and aquatic subsystems to act as a "buffer" for these inputs will decrease without the replacement of acid neutralizing compounds. Also, the cation exchange complex of the soil will eventually become altered or depleted, providing a less suitable environment for plant and microfloral growth in the near-field vicinity of the launch pads. The reduction in acid neutralizing capacity may also result in mobilization of toxic metals (Pb, Cd, Cu, Al, etc) from the soil. These metals may then be carried into surface and groundwaters and bioaccumulate in the food chain. Detailed literature reviews regarding acid deposition effects on terrestrial and aquatic systems can be found in Dillon et al. (1984), Altshuller and Linthurst (1984), Wood (1978), U.S. FWS (1982), U.S. DOE (1984), and U.S. EPA (1980).

Potential environmental impacts resulting from particulate deposition at Launch Pad 39A are highly variable, being dependent on a variety of factors that include such things as:

- the chemical constituents and behavior of the particulates relative to the chemical make up of the receiving system;

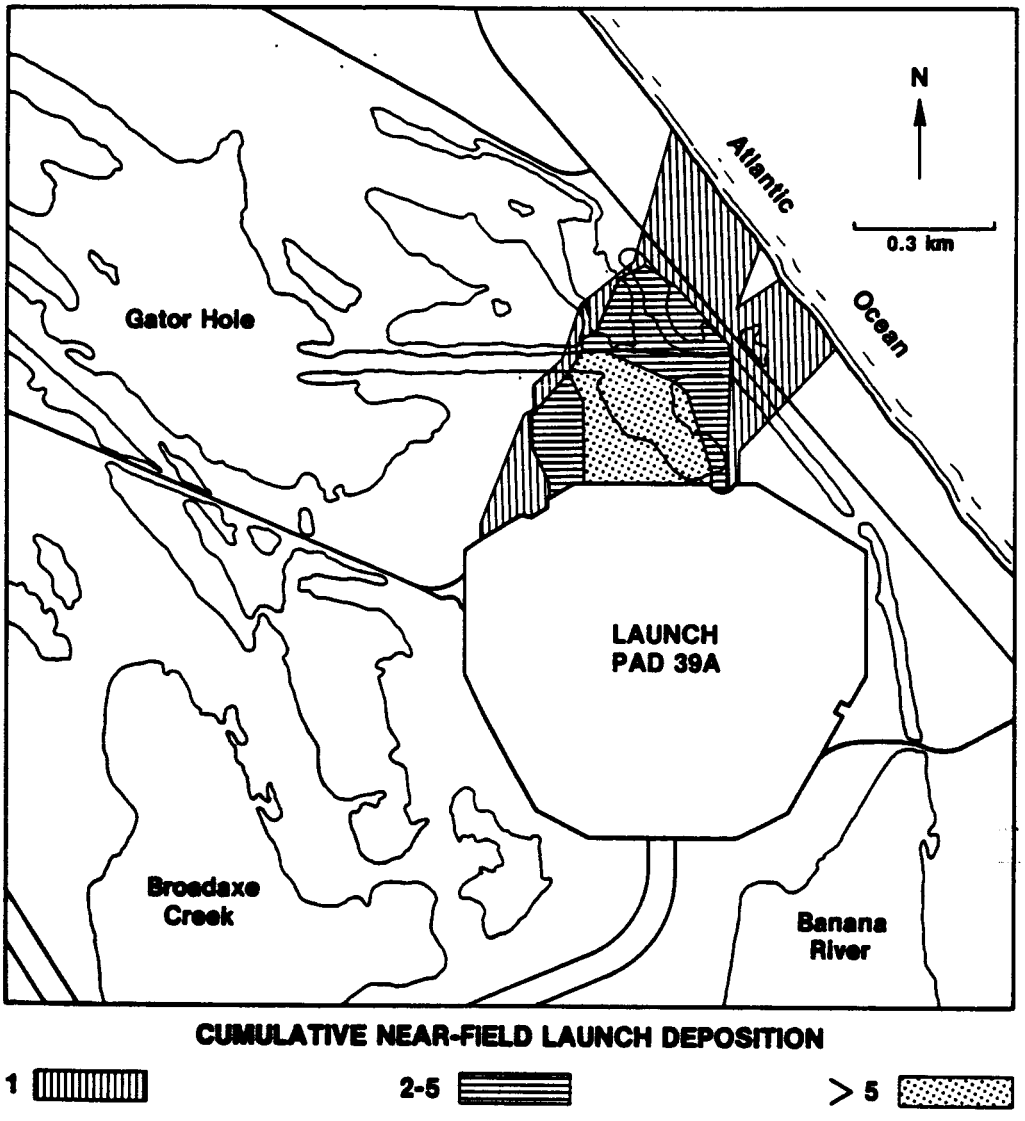

Figure 11. Cumulative near-field deposition patterns produced by the first nine launches of the Space Transportation System as defined by vegetation damage (Schmalzer et al. 1985).

- the size distribution of the particulates relative to the size distribution of particles in the receiving system;
- the biological characteristics and sensitivities of the terrestrial and aquatic communities potentially being impacted;
- the presence and concentrations of other chemicals such as metals and organics, known to have affinities for particulates.

Detailed evaluations of the ecological fates and effects of particulates in aquatic systems have been made by the U.S. Army Corps of Engineers in their investigations of dredged materials disposal (Peck 1982). Olsen et al. (1982) present a detailed review of pollutant-particle associations in coastal marine environments. These association result from: (1) ion exchange, precipitation, or hydrophobic interactions with the particle surface, (2) co-precipitation with iron and manganese hydrous oxide coatings (3) complexation with organic substances bound or aggregated with particles, (4) incorporation into mineral lattices, organisms or fecal material and (5) flocculation. Particulate loading may alter soil and sediment characteristic such as porosity, permeability, cation and anion exchange capacities, and nutrient levels. Potential impacts to aquatic ecosystems at Launch Pad 39A include but are not limited to: (1) increased turbidity and siltation, (2) reductions or alterations of primary production, (3) alteration of benthic habitat characteristics, (4) changes in biogeochemical systems and (5) bioaccumulation of metals in the food chain.

IV. CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated that a substantial amount of chlorides (HCl) and particulates are deposited in the near-field area outside the pad perimeter fence during launches of the STS. It is estimated that under certain wind conditions 3.4×10^3 kg of HCl and 7.1×10^3 kg of particulates are deposited across the 12.6 ha study site. These levels represent worst case areal HCl loading of 1.7×10^3 kg to the aquatic system and 1.7×10^3 kg to the terrestrial system. Particulate loadings to the aquatic and terrestrial ecosystems were 3.5×10^3 kg and 3.6×10^3 kg respectively. Buffering the acid deposition requires an equivalent of 4.7×10^3 kg of $CaCO_3$ from the environment.

Based on these findings it is recommended that the chemical characteristics (metals) and biogeochemical fates and effects of the deposition products be more fully investigated. This should include a detailed evaluation of Launch Pad 39A surface runoff characteristics to determine ecosystem loading rates from this source. A similar program should also be considered for STS launches from Vandenberg Air Force Base which has a different pad configuration.

Particulate deposition entrained in the proximate near-field collectors indicated that large amounts of sand and other debris are also carried by the initial SRB ignition blast. To better understand the variation in particulate loadings it is recommended that the relative particulate size distribution and associated chemical makeup of deposition products across the near-field area be assessed. This information is critical for understanding the potential ecosystem impacts that may result from STS launches.

Estimates of maximum HCl deposition in the study area represented 17 percent of the total produced during the first 10 seconds of the launch event. In addition, measurements of chlorides in the deluge water holding ponds (2,000 kg) represented another 11 percent of the HCl produced. These values strongly suggested that the conservative estimates of ground cloud composition at the height of stabilization utilized in the REEDM model be reconsidered and input values for the model be reduced by at least 20 to 30 percent for HCl. This provides a more realistic computation of far-field deposition which will be useful in assessing the potential for long-term ecosystem effects.

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15. Abstract

The assessment of environmental impacts resulting from launches of the Space Transportation System (STS) requires quantification of deposition patterns and identification of chemical constituents of exhaust products, especially those produced by the Solid Rocket Boosters. During launches 41-B (STS-11), 41-C (STS-13) and 41-D (STS-14) up to 100 bulk deposition collectors, 83 mm in diameter containing 100 ml of deionized water, were placed in a grid pattern covering 12.6 ha north of Launch Pad 39A. Estimates of chloride (primarily in the form of HCl) and particulate deposition patterns and levels were made based on laboratory measurements of materials entrained in the bulk collectors. Estimated maximum ranges of chloride and particulate deposition within the sample area outside the launch pad perimeter fence were from 0 to 127 g/m^2 and 0 to 246 g/m^2, respectively. These measurements represent worst case near-field deposition of approximately 3.4×10^3 kg of chlorides and 7.1 and 10^3 kg of particulates. The impacts should be limited to the near-field area (15-25 ha) in the vicinity of STS launch complexes based on this investigation.

16. Key Words

Space Shuttle Launch, Hydrochloric Acid, Particulates, Deposition Patterns

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